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MASS MOVEMENT RESPONSE TO FOREST MANAGEMENT IN THE CENTRAL OREGON COAST RANGES

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Metric Equivalents

1 inch	=	2.54 centimeters
1 foot	=	0.3048 meter
1 mile	=	1.609 kilometers
1 acre	=	0.4047 hectare
1 cubic yard	=	0.7646 cubic meter

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REFERENCE ABSTRACT

Gresswell, Stuart, David Heller, and Douglas N. Swanston. 1979. Mass movement response to forest management in the central Oregon coast ranges. USDA For. Serv. Resour. Bull. PNW-84, 26 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Timber management activities have clearly accelerated the number and frequency of soil mass movements on the Mapleton District, Siuslaw National Forest as a result of the November 29-December 1, 1975 storm. Exclusive of roads, clearcutting is the most damaging activity.

KEYWORDS: Landslide (-forest damage, erosion -)forestry methods, logging (-erosion, timber management planning.

Research Summary

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Timber management activities have clearly accelerated the number and frequency of soil mass movements on the Mapleton District, Siuslaw National Forest as a result of the November 29-December 1, 1975 storm. The silvicultural practice of clearcutting, unassociated with roads, is the most damaging activity.

Soil resource inventory land type, slope gradient, and aspect exert a strong influence on slope failures. Greater than 95% of all failures inventoried occurred on soil resource inventory units 47, 44 and 41 and on slopes greater than 70 percent. North facing slopes had the largest number of failures (64%) in "in-unit" and "road related" classes. Occurrence of failures within a cutting unit was also strongly influenced by both position on the slope and time since cutting.

CONTENTS

INTRODUCTION

As noted by numerous authors (Swanston 1969 and 1976, Swanston and Dyrness 1973, O'Loughlin 1974, Megahan and Kidd 1972, Rice et al. 1972, Swanson and Dyrness 1975), soil mass movement is probably the dominant erosion process in the steep, mountainous terrain of the Pacific Northwest. The present landforms of much of the Coast Ranges of Oregon are being shaped by active mass movement erosion.

Management-related mass movement erosion has consistently been identified as one of the major environmental impacts associated with forest operations in this naturally unstable terrain.

Following a major storm in November 1975, a field inventory of mass movements, primarily debris avalanches and debris torrents was conducted on the Mapleton Ranger District of the Siuslaw National Forest[1/] (fig. 1). The inventory revealed that more than three-fourths of the 245 failures

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[1/] The inventory was performed by Mapleton Ranger District personnel as an extension of a regular Flood Emergency Road Maintenance mobilization.

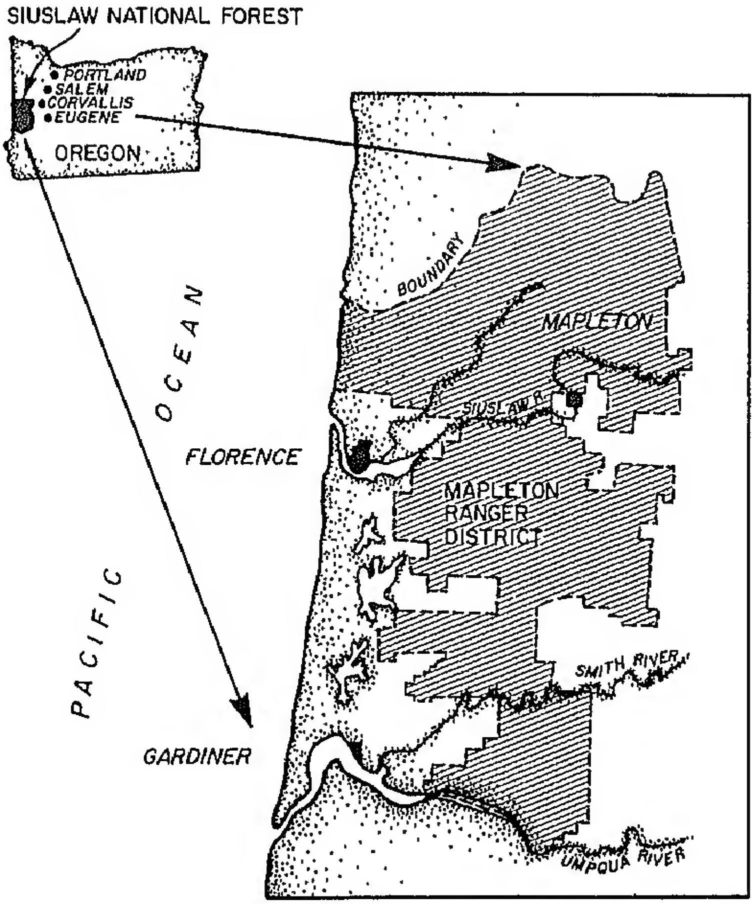

Figure 1.--Location map of the Siuslaw National Forest with an enlargement showing the boundaries of the Mapleton Ranger District.

inventoried occurred within clearcut units with no apparent association to forest road construction. These accounted for more than 60 percent of the total estimated soil volume transported from slopes to stream channels by mass movements in areas influenced by management activities.

Although past research indicates that roadbuilding is the dominant management activity accelerating this type of erosion, results of this inventory suggest that timber harvesting and logging activities, exclusive of roads, produce significant increases in slide frequency and volume of transported soil.

HISTORICAL PERSPECTIVE

Potential soil stability problems related to management activities on the Siuslaw National Forest were first identified in the early 1950's. By 1957, when the timber harvesting volumes began to approach the programed allowable harvest level, multiple use plans for the Smith River and Mapleton Ranger Districts explicitly addressed the critical nature of the soil resource and the potential for accelerated erosion by mass movement activity.2/

After the two Districts were combined as the Mapleton District (July 1972), several major storms hit the area in the winter of 1973-1974. Numerous soil mass movements were triggered during these storms. A large portion was related to land management activities. A specific road failure which entered a nearby anadromous fisheries stream focused the concerns of the State fisheries agency on the apparent acceleration of soil mass movement activity and the associated impacts to watershed resources.3/ Subsequent onsite investigation concluded that inadequate road maintenance was the most likely causal factor for this specific event.4/

2/A chronological summary of events and efforts related to mass soil movement problems is contained in a joint report, "Mass Soil Movement and Stream Damage from Road Construction Activities on the Siuslaw National Forest," by the Oregon Wildlife Commission and Siuslaw National Forest. On file at Forestry Sciences Laboratory, Corvallis.

3/Oregon Wildlife Commission Report, Northwest Regional Office, Salem, Oregon, 1974.

4/USDA Forest Service Storm Damage Report on Mapleton Ranger District for the 1973-1974 water period. On file at Mapleton Ranger District Office, Siuslaw National Forest, Mapleton, Oregon.

The continuing concerns over forest-wide soil stability problems and adequate road maintenance resulted in development of a number of innovative management tools. Two major examples are the Region 6 USDA Forest Service Fish Habitat Management Policy (FHMP) and the Flood Emergency Road Maintenance Plan (FERM). The Fish Habitat Management Policy establishes specific goals for managing fish habitat. One of these is to protect the existing habitat from degradation. An interim directive[5/] provided for the identification of high risk mass soil movement areas in terms of potential fisheries habitat damage. The FERM plan stresses various alert levels dependent on rainfall volume and intensity. This plan mobilizes personnel and heavy equipment in order to minimize, control, clean up, and document storm damage along District roads.

During the same time period that the FHMP and FERM plan were being developed, the Siuslaw National Forest initiated a forest-wide resource inventory process in preparation for timber management and land use planning. The Soil Resource Inventory (SRI)[6/], one of these planning level inventory tools, identified and mapped major landform units in the District and provided profile characteristics representing the dominant soil that would be found on that landform unit. A special refinement of the SRI included a landslide inventory and the development of relative stability ratings for most of the mapping units.[7/]

During the winter of 1975-1976, another major storm hit the forest. It started on November 29 and ended on December 1. Approximately 7.75 inches of precipitation were recorded at the office of the Mapleton Ranger District as a result of this storm. The most intense rainfall occurred on Sunday, November 30. During a 6-hour period, 3.0 inches of rainfall were recorded.

On Sunday evening, the District Ranger implemented the FERM plan to mobilize personnel and equipment as early as possible the next morning. Within 2 days, an accurate overview of the location and relative magnitude of the major road and in-unit soil mass movements was obtained. Recognizing the opportunity to gain valuable information

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[5/] This FHMP interim directive is no longer in effect.

[6/] Soil Resource Inventory, Siuslaw National Forest, USFS Pacific Northwest Region, 1974, originally performed by Harold Legard, LeRoy Meyer and George Badura and refined by Donald Boyer. A copy is on file at the Siuslaw National Forest, Corvallis, Oregon.

[7/] The SRI Landslide Inventory was performed by Laurence Rich and the landslide risk ratings developed by Donald Boyer, Laurence Rich, and George Badura. Siuslaw National Forest, Corvallis, Oregon.

relating soil mass movements to management activity, District watershed management specialists conducted a comprehensive field inventory of the storm damage. The major objective of the inventory was to define and quantify the nature and magnitude of mass movements resulting from this specific storm event.

From this inventory data, comparisons were drawn between the occurrence and magnitude of mass movements and existing SRI debris avalanche risk ratings, as well as other environmental parameters. Such comparisons and the quantitative information obtained during subsequent field and office investigations are the basis of this study.

METHODOLOGY

The field inventory was performed by two District two-man teams. One team was responsible for checking the north half of the District and the other the south half. Each team carried a District fire map, which was used to indicate completed survey areas, and color aerial photographs (scale 1/15,850) on which to mark the location of individual mass movements. Roads were inventoried by vehicle, and most units were partially walked so that all drainages and headwalls were observed.[8] Approximately 70 percent (144,200 acres) of the District's land area was inventoried. Only mass movements which entered a drainageway and whose volume exceeded 10 cubic yards were counted. Road backslope failures were excluded unless they met the requirements above.

Information on an event was recorded on a standard data sheet (fig. 2). Slides were first placed in one of three major categories: natural, road-related, or in-unit. Natural slides were those events which had no apparent relation to management activity (fig. 3). Road-related failures were those failures which occurred within the road prism or had an obvious connection to the road (fig. 4). Typically, those were from a concentration of drainage water by ditchline and culvert outfalls or by ditchline obstruction. Slides occurring at the edge of landings were considered road related. Those which occurred within the boundaries of clearcut units and had no apparent relation to roads or landings were in-unit slides (fig. 5).

Slope angle was measured at the head of each slide using a clinometer. Aspect of the slope at the site was recorded, using a Silvacompass, as one of eight classes--each containing 45° of azimuth (see fig. 2). Other variables included apparent point of origin on the slope, slide dimensions, and estimated length of stream channel scour. Stream scour was determined through visual estimation and measurement from aerial photographs.

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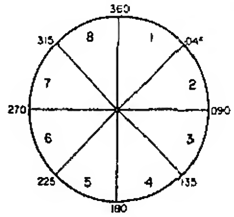
[8] Headwall - the steep, concave slope at the upper end of a drainage formed primarily by debris avalanche processes.



SLIDE DATA SHEET

SLIDE NO. ____________________

Type: Debris Slide ________________ Slump/Earthflow ____

Soil Type ____________________ Slope Angle ____________ Aspect __________

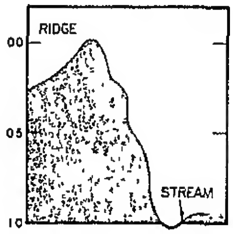
Origin:

Unit Name __________________ Road No. ________ Natural

When Cut ____________________ When Built _______________ Remarks _____________

Yard Syst. __________________ Sidecast __________ Full Bench _________________

Below Landing ____________ Soil Hazard Rating ______________



Apparent Point of Origin ______________________

Vegetative Cover _____________ % Species __________________________________

____

____

Estimated Ft. Channel Scour ______________ Jams ___________ Remove ____________

Likelihood Future Failure ____

____

Remarks: ____

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Figure 2.--Landslide data sheet used for slope failure inventory.

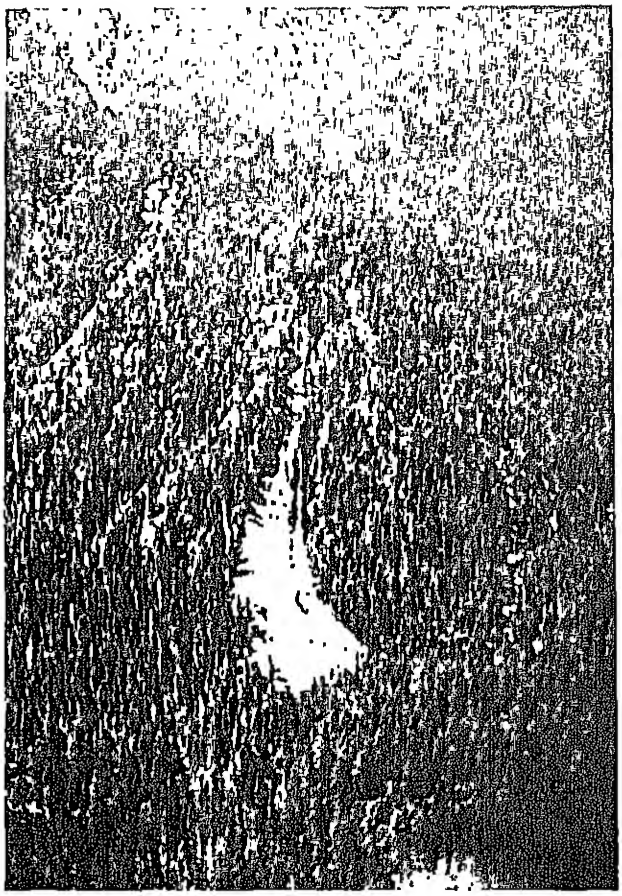

Figure 3.--Debris avalanche on an undisturbed slope.

Figure 4.--Debris avalanche resulting from a road prism failure.

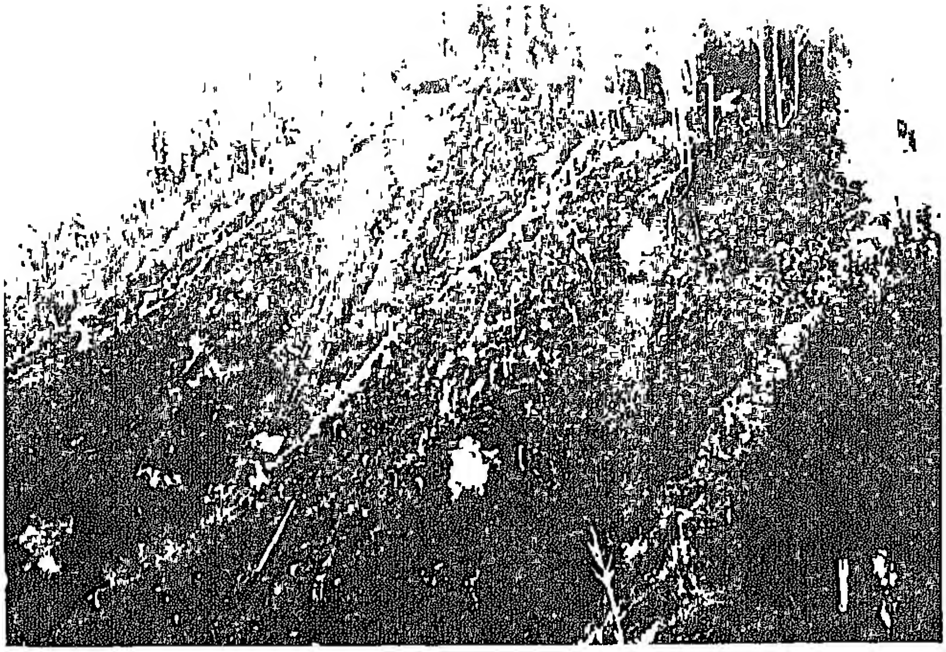

Figure 5.--Debris avalanche developed in clearcut units.

Numbers of slope failures and estimated volumes released to the channel by land-use category are shown in figure 6.

Dominant soil at the site where the slide had occurred was determined using Forest Soil Resource Inventory (SRI) descriptions and quadrangle maps. Since the SRI mapping units are not designed to be site-specific in terms of soil type, individual judgment was used to identify the actual soil type at the slide site by comparison with characteristic profiles of the dominant soil type for each mapping unit. These determinations were later field checked by the Siuslaw National Forest soil scientist.

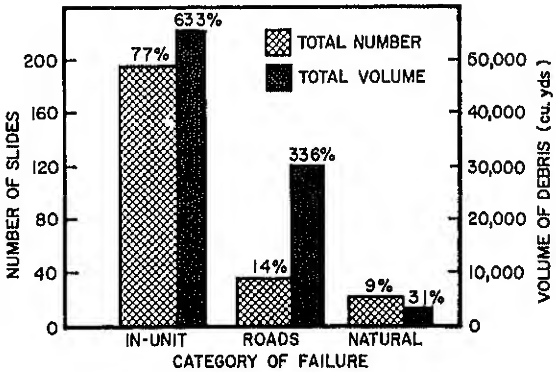

Figure 6.--Graph showing number of slope failures and estimated volumes of debris released by land-use category.

Data Analysis

At completion of the field inventory, data sheets were separated into three categories (natural, road-related, or in-unit landslides) and information transferred to data summary sheets for analysis. The summarized data are reported in tables 1 through 4. Using these data, comparisons were made between number of landslides, category of landslide, and the independent variables:

1. SRI unit
2. Slope steepness
3. Aspect
4. Slope position
5. Time (years since cutting)

Table 1--Characteristics of the 22 inventoried natural failures in terms of Soil Resource Inventory unit, slope and aspect

1. Natural slides as related to site specific SRI mapping units

Unit no.	Number	Percentage
47	6	27
44	7	32
41	9	41

2. Natural slides as related to slope steepness class

Steepness (%)	Number	Percentage
0-59	1	4
60-69	0	0
70-79	4	18
80-89	12	55
90 +	5	23

3. Natural slides as related to slope aspect class

Aspect class	Number	Percentage
NW	5	23
NE	5	23
SW	4	18
SE	8	36

Table 2--Characteristics of the 34 inventoried road-associated failures in terms of Soil Resource Inventory units, slope, aspect, and road drainage

1. Road associated slides as related to SRI unit

Unit no.	Risk class*	Number	Percentage
47	5	13	38
44	4	8	24
41	3	11	32
42	2	1	3
51	4	1	3

*For debris avalanche from road right-of-way.

2. Road associated slides as related to slope steepness

Steepness (%)	Number	Percentage
0-59	1	3
60-69	1	3
70-79	4	12
80-89	19	56
90 +	9	26

3. Road associated slides as related to slope aspect class

Aspect class	Number	Percentage
NW	8	24
NE	14	41
SW	2	6
SE	10	29

4. Road associated slides as related to road drainage (ditchline or culvert outfalls)

Total number of road failures	Drainage related	Percentage
34	16	47

Table 3--Characteristics of the 189 inventoried in-unit failures in terms of Soil Resource Inventory units, slope, clear-cut age, aspect and point of initiation

1. In-unit failures as related to SRI unit

Unit no.	Risk class*	Number	Percentage
47	5	83	44
44	4	54	29
41	4	45	24
42	3	6	3
43	3	1	1

*Risk class for debris avalanches from clearcut harvesting

2. In-unit slides as related to slope steepness class

Steepness (%)	Number	Percentage
0-59	3	1
69-70	5	3
70-79	21	11
80-89	60	32
90 +	101	53

3. In-unit slides as related to time (years) since timber felling

Time (Years)	Number*	Percentage
0-3	120	63
4-10	54	29
11 +	12	1
Age unknown	3	2

*Unit ages for three failures were not found, percentages were based on a total of 189 slides.

4. In-unit failures as related to slope aspect class

Aspect class	Number	Percentage
NW	56	30
NE	65	34
SW	32	17
SE	36	19

5. In-unit slides as related to the upper point of headward slide migration1/

Upward point class	Number 2/	Percentage
^	40	21
	92	49
		29

slope

.ained.

Table 4--Landslide related impacts[1] to District streams

1. Stream miles impacted by all categories of soil mass movement

Stream class	Total miles	Impacted miles	Percentage of total
CLASS I	315	240	76
CLASS II	139	23	16
CLASS III	238	14	6

2. Length of stream channel mechanically scoured as related to categories of mass movement

Category	Feet of channel scour	Miles	Percentage
Natural	17,700	3.35	19
Road-associated	26,140	4.95	29
In - unit	47,395	8.98	52
Total	91,236	17.28	

[1] The impacted segment of a stream is any part of the drainage system which is downstream from the point where material from a mass movement has entered the stream. This is based on the assumption that this material will be transported through the entire downstream drainage. No effort was made to differentiate the degrees of impact throughout individual drainage systems.

This study was not a statistically designed experiment, but simply a case history of the impacts of management-related activites on soil mass movement generation during a single storm event. Within the limitations imposed by access and terrain, all failures occurring as a direct result of the November 29-December 1, 1975 storm were enumerated, thus, we have assumed that the entire population has been measured. The frequencies which are reported are population parameters and any differences which exist in frequencies by class are real differences.

Of the 245 inventoried slope failures resulting from the November 29-December 1, 1975 storms, 22 or approximately 9 percent were natural events with no apparent association with management activity (table 1). In terms of frequency, this is approximately one failure per 6,129 acres (1/6,129) of uncut timber. Thirty-four of the inventoried failures, or approximately 14 percent, were road-associated, occurring within the road prism or directly associated with road

drainage (table 2). This is about one failure per 85 acres (1/85) of road right-of-way or one failure per 14 miles of road.[9] The largest number, 189 failures or approximately 77 percent, were in-unit failures having no apparent association with roads or landings (table 3). Most of these occurred within headwall areas or on the mid-slope, in or adjacent to class I streams[10] and incipient drainages loaded with organic debris. The calculated frequency of occurrence for these in-unit failures is one slide per 261 acres (1/261). The differences in frequency between land-use categories are large. There are more failures per given area along road right-of-way than within clearcut units. If, however, the higher frequency for road-related failures is weighted in terms of total area impacted by management (assuming 5 percent of area influenced by road construction and 95 percent of area in clearcut units), the frequency resulting from road impact is reduced to one failure per 1,540 acres (1/1540). This is more than a fivefold increase in failure frequency (5.57) within clearcut units over roads.

A similar analysis by Swanson and Dyrness (1975), based on a 25-year history of landslide activity on the H. J. Andrews Experimental Forest in the western Cascade Range, points out that while roads accelerate debris avalanche erosion to a much greater extent than clearcutting in terms of frequency, rights-of-way cover much less area than do clearcut units. When road and clearcutting are weighted by the area influenced by each activity, the two types of activity contribute about equally to the level of accelerated erosion.

Damage resulting from these mass movement processes was extensive in terms of total stream miles affected, the amount of mechanical scouring occurring within the stream channel, and total volume of soil and debris introduced into the stream (table 4). Of a total of 315 miles of class I stream within the District, 76 percent (240 miles) was

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[9] Road acreage estimates are based on a 50-foot right-of-way width being approximately 6 acres per mile.

[10] Class I - a perennial or intermittent stream or sections thereof having one or more of the following characteristics:

(a) Direct source of water for domestic use (cities, recreation sites)
(b) Used by large numbers of fish for spawning, rearing, or migration
(c) Enough water flow to have a major influence on water quality of a class II stream.

impacted[11] by all categories of slope failure. From the total of 139 miles of class II channel,[12] 16 percent or 23 miles was impacted. Of a total of 238 miles of class III channel,[13] 6 percent or 14 miles was impacted.

Mechanical scouring was the clearest impact to identify and define during the inventory (figure 7). It was possible to correlate scour directly with failure category. Thus, of the total length of channel scour observed (91,236 feet or 17.28 miles), 52 percent (47,395 feet or 8.98 miles) occurred as the result of in-unit failures. Road related failures accounted for 29 percent of about 26,140 feet (4.95 miles) of scour. Natural failures produced 19 percent or 17,700 feet (3.35 miles) of scour. All of these channel scour estimates are conservative.

Differences in volume of debris added to the channel, obtained from estimates of failure dimensions during the inventory, were also large (figure 6), and suggest that in-unit landslides added more debris volume to stream channels than road and natural categories combined. The total estimated volume of all categories was 87,090 cubic yards. Of this total volume, approximately 63.3 percent or 55,100 cubic yards resulted from in-unit failures and 33.6 percent or 29,240 cubic yards from road-related failures. Only a small percentage (3.1 percent or 2,750 cubic yards) was contributed by natural failures, based on a limited sample size.

Of considerable interest is the average volume released per failure in each of the three categories. Natural failures were quite small, averaging only 125 cubic yards per failure. In-unit failures averaged 290 cubic yards per failure or about twice as large as those occurring under natural conditions. Road-related failures, while fewer in number, were by far the largest, averaging 860 cubic yards per failure or about a seven times increase in volume over natural failures.

[11] The impacted segment of a stream is any part of the drainage system which is downstream from the point where material from a mass movement has entered the stream. This is based on the assumption that this material will be transported through the entire downstream drainage. *No effort was made to differentiate the degrees of impact throughout individual drainage systems.*

[12] Class II - a perennial or intermittent stream or sections therefore having one or more of the following characteristics:

(a) Used by moderate though significant numbers of fish for spawning, rearing or migration.

(b) Enough water flow and not clearly identifiable influence on downstream quality of a class I stream, or have a major influence on a class II stream.

[13] Class III - All other perennial streams or segments thereof not meeting higher class criteria.

Figure 7.--Channel scour in a class I stream result from a debris torrent.

It should be pointed out that total slide volume (volume leaving slope + volume entrained in debris torrent) was not estimated. Therefore, these volumes are extremely conservative in describing the total slide erosion volume which occurred.

Natural failures as a result of this storm appear to be of minor importance in terms of numbers of occurrence, frequency, and amount of channel damage. Total numbers, size, and frequency of occurrence were all low compared to management-related events. Caution must be taken in interpreting these data, however, since emphasis was placed on management-related occurrences, all of which can be easily identified and described. All observable natural events were recorded; but an unknown number, occurring at inaccessible sites or too small to see under heavy forest cover, were missed.

The number of road-associated failures is low compared to data reported elsewhere in the Pacific Northwest. Dyrness (1967), investigating accelerated soil mass movements on the west flank of the Cascade Ranges following heavy rains in the winter of 1964-1965, found 65 percent directly associated with roadbuilding. In Idaho, Megahan and Kidd (1972) reported 90 percent of the soil mass movements which occurred along the south fork of the Salmon River during a storm in April 1965, resulted from failures along the logging road right-of-way. Recent studies of accumulated landslide activity related to timber harvesting in the Pacific Northwest over extended periods of time (Fiksdal 1974, Morrison 1975, Swanson and Dyrness 1975) reported 70 percent of all landslides generated were related to road rights-of-way. In all cases, the greatest number of these resulted from road-fill failures. The low frequency of road related events on the Mapleton District may be directly related to the implementation of the District FERM plan and improved road design and construction techniques. The principal intent of the plan was to reduce road failures by having personnel patrol roads and clean culverts to prevent ponding and damming of water during storms.

The greatest amount of landslide activity and resultant watershed damage was produced from failures occurring within clearcut units unassociated with roads. This strongly emphasizes the importance of logging operations, exclusive of associated activities, as a generator of accelerated soil mass movements on steep, forested slopes. Bishop and Stevens (1964) working in southeast Alaska demonstrated a direct correlation between timber harvesting and accelerated soil mass movements following heavy rains in the fall of 1961. They report an increase in landslide frequency of 4-1/2 times following clearcut logging exclusive of roads. Croft and Adams (1950), reporting on landslide increases following timber harvesting in the Wasatch Mountains of Utah, attribute accelerated landslide activity chiefly to timber cutting and burning.

Dominant soil characteristics, slope dissection, slope steepness, and aspect exerted significant control on debris

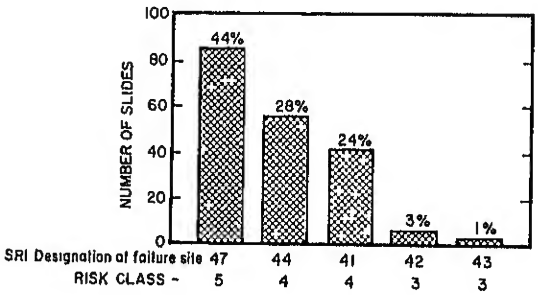
avalanche occurrence during the storm. There is a strong relationship between landslide frequency and SRI units with more than 96 percent of inventoried failures occurring within the group of "high risk" units (units 41, 44, and 47). All three types have dominant soils derived from residuum and colluvium over micaceous sandstone.[14]

The dominant soils in each category possess surface soils which are characteristically thin, gravelly, sandy loams to loams. Subsoils are thin loams and gravelly loams with a depth to bedrock of less than 3 feet. All occur on slopes between 50 to 90 percent. Unit 41 soils typically contain more clay. Unit 47 soils typically contain more cobbles. All three types are similar in engineering properties, being essentially nonplastic, inorganic silts with some sand and gravel. Maximum bulk densities are low. Such soils possess little cohesion when saturated and a low enough permeability so that they may be susceptible to rapid increases in pore-water pressure during major storms due to the presence of excess water. Under these conditions, the coefficient of friction may be reduced from a range of 27-30° to a range of 20-22°, greatly reducing resistance to shear of the soil (Terzaghi and Peck, p. 86, 1960).

Despite the similarity in physical properties and slope occurrence of dominant soils in the "high risk" category, a large difference is also indicated for the frequency of occurrence of in-unit failures on each of these units (fig. 8). These differences are probably due to degree of dissection of the slope.

Based on SRI unit characteristics, unit 41 slopes are smooth to moderately dissected. Unit 44 slopes are moderately to highly dissected, and unit 47 slopes are highly to extremely dissected. For purposes of this analysis, degree of dissection is defined in table 5.

Figure 8.--Number of in-unit slides versus SRI mapping unit. Risk class 4 at 24 percent is considered a 3 on a forest-wide basis, however, Mapleton Ranger District considers it risk class 4.



[14] Soil Resource Inventory, Siuslaw National Forest, basic soil information and interpretive tables. USDA Forest Service Pacific Northwest Region, 1974, copy on file at the Siuslaw National Forest office, Corvallis, Oregon.

Table 5--Table of dissection criteria used by field personnel of the Siuslaw National Forest

Dissection	Centerline spacing between drainages (feet)
Extreme	400
High	400 - 700
Moderate	700

The largest number of failures in clearcut units occurred within SRI unit 47 (83 out of 189 or 44 percent). This is probably because of the larger number of potential failure sites along existing drainages and incipient channels on these highly to extremely dissected slopes. SRI unit 44 accounted for 54 in-unit failures or about 28 percent, and SRI unit 41 produced 46 or about 24 percent. SRI units 41 and 44 exhibit similar degrees of relative landslide activity, probably due to the dominance of moderate dissection for both these units. This suggests that dissection exerts a strong degree of control on landslide occurrence for clearcut slopes.

Slope steepness is also an important factor in landslide generation with 95 percent of all inventoried failures occurring on slopes greater than 70 percent (31.5 degrees). For natural and road-related failures, the greatest number occurred on greater than 80-percent (36 degrees) slopes (77 percent of natural failures and 81 percent of road-related failures). The greatest number of in-unit failures occurred on slopes above 90 percent (40.5 degrees, approximately 53 percent of all failures). This corresponds to about the upper limit of the angle of internal friction for inorganic silts in the absence of water. In the presence of saturated conditions, slopes above this 70-percent gradient can be expected to be in a highly unstable state.

Similar distributions of slope failure gradient have been reported for other areas. Dyrness (1967) reports the greatest number of debris avalanches occurring on slopes above 22.5° (50 percent) following logging and burning on the H. J. Andrews Experimental Forest, western Cascade Range of Oregon. Bishop and Stevens (1964), after measuring and profiling 15 debris avalanches in clearcut units following a major storm in southeast Alaska, report a minimum angle of release of 31° (70 percent) with a mean of all slides of 39° (87 percent). O'Loughlin after a study of 77 debris avalanches in the Coastal Mountains of British Columbia reported a

minimum angle of release of 30° (67 percent) with a mean of 36° (80 percent).[15]

Aspect or exposure was the least important common factor in landslide generation during the November 30 storm. Natural landslides were nearly equally distributed on northerly and southerly slopes, although the small sample size limits the reliability of this observation. For the occurrence of management-generated failures, however, there is a strong relationship to aspect class. Approximately 64 percent of road-related and in-unit failure occurred on northerly aspects. The higher frequency of landslides on north slopes is probably directly correlated with local structure. Parent material and structure have been identified repeatedly in the literature as exerting a controlling influence on the type and frequency of soil mass movements on steep, forested slopes (Swanston 1967 and 1971, Dyrness 1967, Megahan 1975, Fredriksen and Ross 1975, Swanston and Swanson 1976). Under a given set of climatic conditions, parent material controls depth, degree of weathering, and weathering products. Structure (bedding, faulting, fracturing, jointing) determines location and distribution of potential failure surfaces, and dictates movement and distribution of subsurface water. The topography of the Mapleton District is characterized by east-west trending, narrow ridges separated by deeply incised drainages. These ridges are developed in massive to thinly bedded sandstones and siltstones striking northwest and dipping gently to the southwest.

Well developed north-trending jointing is superimposed on this basic structure. The slopes are steeper on the north aspect with the gradient apparently controlled by this jointing.

Slope position for in-unit failures appears to exert a considerable influence on landslide occurrence with 78 percent of the inventoried failures located on the mid-slope or at stream-adjacent sites (fig. 9).[16]

Of the failures inventoried, 92 or about 49 percent occurred in the mid-slope position within incipient drainages where ground water movement from the upper slopes probably produced saturated or near saturated conditions in the soil mantle. Fifty-five or approximately 29 percent occurred at the bottom of the slope adjacent to stream channels and were

[15] Colin Lockhard O'Loughlin, 1972. An investigation of the stability of the steepland forest soils in the Coast Mountains, Southwest British Columbia, 147 p., Ph.D. thesis on file, Faculty of Forestry, the University of British Columbia, Canada.

[16] Slope position as reported here refers to the position on the slope between the ridgetop and the first intersected drainage. This may be a class I, class II, or class III drainage (see footnotes 10, 12, and 13).

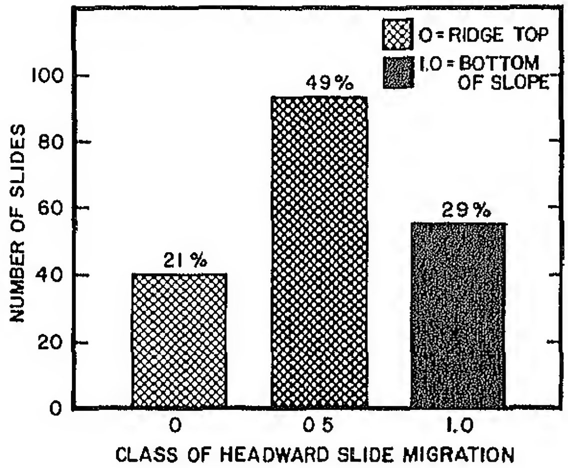


Figure 9.--Number of in-unit slides versus slope position.

probably initiated by lateral cutting along channel banks by storm flow. The remaining 40, or about 21 percent, occurred near the ridgetop in exceptionally steep slope positions.

Time since timber felling also exerted a significant control on number and frequency of in-unit slope failures (fig. 10). Of the 189 inventoried failures in this category, 120, or 63 percent, occurred on clearcut units harvested within the 3 years preceding the storm. Fifty-four failures, or 29 percent, occurred in units cut less than 10 years prior to the storm. Only 12, or about 1 percent of the total, occurred in clearcut units older than 11 years, strongly emphasizing the importance of timber cover on the relative stability of these potentially unstable slopes.

The principal impacts of forest removal by clearcutting are to reduce rooting strength and to alter the hydraulic regime at the site. Swanston (1974) describes the mechanical support provided by vegetation roots as a dominant factor in

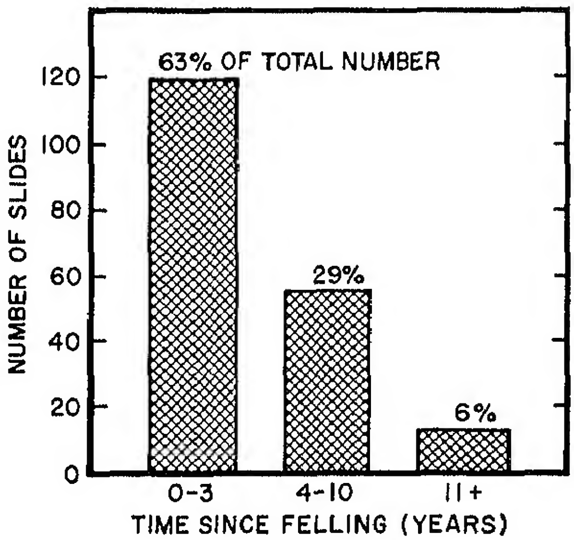


Figure 10.--Incidence of in-unit slides as related to time since timber felling. Age was indeterminant for three clearcut areas accounting for 2 percent of total.

maintaining the shear strength of many steep-slope forest soils in western North America. In Japan, Kitamura and Namba (1966 and 1968) describe a period of greatly reduced soil strength attributable to root decay beginning about 3 years following cutting and attaining a minimum strength 15 years after harvest. Bishop and Stevens (1964) reported a 3- to 5-year lag between clearcutting and accelerated slope failure rates in southeast Alaska. From strength tests on roots taken from clearcut units of various ages in this region (Ziemer and Swanston 1977) a decrease of more than one-half in Sitka spruce and one-third in western hemlock root strength was demonstrated in the first 2 years after cutting. O'Loughlin, after approximately 200 tests of strength loss in roots from Southwest British Columbia, concluded that Douglas-fir roots lose more than half their strength in the first 3 years following clearcutting (see footnote 15).

The hydrologic impacts of timber removal include modification of annual soil-water status and changes in peaks of soil water held in detention storage during periods of storm runoff (Swanston and Swanson 1976). Increases in soil water during storms (due to timber removal) can generate active pore-water pressures, triggering shallow debris avalanches and debris torrents. Reduced evapotranspiration results in soil water status remaining at higher levels for longer periods of time resulting in more rapid saturation and active pore-water pressure development during storms. Timber removal may also increase peaks of soil water by accelerated snowmelt during warm-rain-on-snow conditions (Anderson 1969).

CONCLUSIONS

Timber management activities have clearly accelerated the number and frequency of soil mass movements on the Mapleton District, Siuslaw National Forest, as the result of the November 29-December 1, 1975 storm. Clearcut harvesting, exclusive of roads, stands out as the most damaging activity with over three-fourths of the generated failures and about two-thirds of the released volume of debris occurring as a result of this activity. Less than one-fifth of the storm-generated failures occurred within the road rights-of-way and they produced only one-third of the total volume of debris. The impact of forest roads relative to clearcuts is considerably smaller than reported elsewhere, suggesting that the special efforts made by District personnel in overall improved road location, design, construction practices, and maintenance of drainages and culverts during the storm had a substantial effect on reducing road-generated failures. Although the number of failures and total volume of debris produced was significantly lower from road rights-of-way, the average volume per slide was approximately seven times that of natural failures and approximately two times that of in-unit failures. This strongly emphasizes the potential

for maximum damage from road-related failures if adequate design and maintenance are not continued.

Slope gradient, SRI units, and aspect exerted a strong influence on occurrence of the slope failures generated during the November 29-December 1 storm. Most of the failures occurred on high risk SRI units 41, 44, and 47. Major differences in failure were noted between units. Of these three, unit 47 accounted for more than one-half of all failures with the rest distributed between units 41 and 44. SRI unit 47 has the highest degree of dissection and highest slide frequency, perhaps because degree of dissection determines the number of locations at which failures can occur.

Most of the failures inventoried occurred on slopes greater than 70 percent (31.5 degrees). Slopes of this gradient are near their maximum angle of natural stability and are highly susceptible to any activities which may reduce their strength-stress ratios.

North facing slopes had the largest number of failures, particularly for the in-unit category. Too few inventory samples of natural failures were obtained to develop this relationship. Roads tended to mask the aspect relationship because of the dominating influence of road drainage on slide generation.

In-unit failures were strongly influenced by both position on the slope and time since cutting. Almost one-half of all the in-unit failures occurred at the midslope position, from one-third to two-thirds of the way between the ridgetop and the first intersected drainage. Such a position allowed for maximum development of saturated soil conditions due to upper slope drainage. Almost one-third of the in-unit failures occurred at sites adjacent to streams and were probably initiated by undercutting of slopes during stormflow or debris torrent activity. The remaining failures occurred near the ridgetop and may have developed on exceptionally steep faces, triggered by excess water from local spring flow.

Almost two-thirds of all in-unit failures occurred in clearcuts harvested less than 4 years before the storm. Most of the remaining failures occurred in units cut less than 11 years before the storm. The dominance of failures in the 0- to 3-year bracket suggests that removal of timber canopy and deterioration of root systems may exert a substantial effect on landslide generation on this potentially unstable ground.

Benefits to Ongoing Management Programs

Information from this inventory provided input to both short- and long-range management decisionmaking. Perhaps most importantly, it provided the District Ranger and his staff with a quantitative overview of mass movement activity on the District. The inventory related soil mass movements

to: location (both geographically and topographically), general management categories (roads or clearcuts), impacts to resources (frequency and volumes as related to soils and stream systems), and to winter storms with a return frequency of about 1 in 10 years. By defining landsliding on a District-wide basis, efforts have been more effectively focused toward short- and long-range problem solving. Immediate changes in timber sale planning efforts are a short term response. More time and effort during sale planning has been focused upon location of potential "high risk" landslide areas. On a regular basis, protective or mitigative management prescriptions are now routinely applied. This most commonly involves vegetative leave areas on high risk headwalls and slopes adjacent to streams.

The inventory provided significant immediate benefits by locating where landsliding had occurred. Using mapping done during the inventory, the District was able to quickly formulate a very comprehensive request for road repair ERFO (Emergency Repair Federal Other) and Emergency Flood Rehabilitation, Section 216 funds. This mapping located potential sites for future flood damage and made project reconnaissance much more efficient. Ultimately, more than $260,000 was received for rehabilitation work. Without such an inventory, this comprehensive work would not have been possible in the time allotted.

The information derived gave very positive, quantitative indications about the efficiency of various road location, design, and construction techniques presently being employed on the District. It also pointed to the importance of road maintenance, particularly road drainage, in controlling road-related slope failures.

The inventory also served to substantiate and further define the risk ratings given to various mapping units under the FSRI. Such information made the relative risk ratings much more of a quantitative and understandable measure for District personnel.

Longer term benefits, resulting from the inventory, included quantitative inputs into ongoing timber management and land use planning and identification and prioritizing of research needs regarding landsliding and soil stability and impacts to other resources, particularly water and fisheries.

Economic Analysis and Future Application

This field inventory approach presents land managers with a reliable tool for gathering quantitative data on mass movements. The total cost of the inventory was about $5,300. Table 6 shows the breakdown of these costs.

Personnel costs accounted for 77 percent of the total cost. These costs were held down by using Comprehensive Employment and Training Act employees as assistants. Vehicle and photographic costs accounted for the remaining 23 percent

Table 6--Component breakdown of inventory costs

	Man days	Cost	% of total
1. Personnel costs (total)	110	$4,100	77
a. Field inventory Two (2-man) teams[1/]	(100)	(2,900)	(55)
b. Data analysis and compilation	(10)	(1,200)	(22)
2. Transportation			
(Two 1/2-ton pickups)		950	18
3. Photography		250	5
Total cost		$5,300	100

[1/] Teams composed of (GS-9) Forester, (GS-7) Fishery Biologist, two Comprehensive Training Act employees.

of the total. About 70 percent of the area of the Mapleton Ranger District, or 140,000 acres, was inventoried. The information gathering costs averaged about 4 cents per acre for the total inventory area. Much more complete reconnaissance, however, occurred along roads and in clearcut units. These areas totaled about 33,500 acres. The cost, considering only these areas, was 16 cents per acre. These costs likely compare very favorably with other field inventory procedures. Stand examinations presently cost an average of $3.00-$6.00 per acre on the District. Limited stream survey work presently averages $35-45 per acre.

With increased emphasis on project and program evaluation in the Forest Service, this type of inventory process to evaluate soil stability conditions appears readily adaptable to ongoing land management programs. The application is flexible to both manpower and funding limitations.

Given basic training in landslide identification and in information gathering required by the inventory form (see fig. 2), a wide variety of personnel could be used to perform such an inventory. They need not be soil scientists. They need only be able to recognize a landslide, to perform some basic measurements and observations, and to record information on a data form. The inventory, as reported in this paper, if performed by two GS-5 Foresters, two Comprehensive Employment and Training Act (CETA) employees, and a GS-9 Soil Scientist or Geologist for training and data analysis could have been performed for a cost of about $4,000.

Another means of adapting this inventory process to funding and manpower limitations is to accomplish it yearly but on a reduced scale. For example, the Mapleton Ranger District could be divided into three inventory areas. Each year, one of the areas would be inventoried so that every 3 years a District inventory is completed. Although such a method would not be sensitive to individual storm events, it would provide continuous information feedback to the land manager regarding landsliding. Such information should indicate changes in total numbers, frequency, locations, etc., of landslides as improved management techniques (road location and construction, timber sale layout and harvesting) are implemented. Over time, such an ongoing inventory program should even allow for objective comparison of various management prescriptions and the ultimate selection of the most efficient prescription in terms of limiting the occurrence and magnitude of landsliding.

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